EOS Validation Investigation Annual Report

Title: Validation and Correction for the Terra MODIS Spatial Response
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Summary

The following accomplishments are reported this year: (1) completed analysis of pre-launch data for the MODIS Terra sensor, (2) acceptance of three conference papers for publication and (3) participation of one of our graduate research assistants in a 1999 summer internship and workshop at NASA/GSFC. The pre-launch analysis partially characterized the MODIS Terra Far-Field Response (FFR), the focal plane registration, and the Modulation Transfer Function (MTF), using the SpectroRadiometric Calibration Assembly (SRCA). Two of the conference papers were accepted to The Society for Optical Engineering's (SPIE) 45th Annual Meeting and the other to the IEEE International Geoscience and Remote Sensing Symposium (IGARSS) 2000. The MODIS Land Science Support Team at NASA/GSFC supported the internship for Francisco Rojas, and the University Space Research Association supported his participation in the summer 1999 workshop on high performance computing.

Significant results from our project to-date are:

- The pre-launch test data and our vegetation index simulation analysis indicate that the FFR can cause significant error in MODIS vegetation science products. We plan to investigate this further in the coming year.
- Our analysis of pre-launch SRCA and IAC data indicates that the SRCA may be a useful tool for on-orbit MTF measurements, and we have incorporated on-orbit SRCA analysis into our research plan.
- The initial MODIS images acquired of the All-American Canal (AAC) near Yuma indicate that it will be useful for MTF analysis for the 250 and 500m bands. The contrast in the 1000m bands is likely to be too low for MTF measurements, but we have not yet looked at that data. Lake Tahoe, a high contrast edge target, appears useful at all resolutions in the initial images.

In order to further characterize the MODIS MTF on-orbit, we plan the following tasks in the coming year:

- MTF analysis using ground targets and image comparison to ASTER and/or Landsat-7 ETM+
- ground truth field trips coinciding with satellite overpasses of our ground targets
- development of MTF correction algorithms and evaluation of MTF correction on certain MODIS science products, particularly Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI)
- characterization of MTF stability

Together, these activities will achieve our primary research goal, validation and correction of the MODIS spatial response. Copies of this report and our other publications are available at *http://www.ece.arizona.edu/~dial/modis*.

1.0 Accomplishments

1.1 Calibration of the MODIS PFM SRCA for On-orbit, Cross-track MTF Measurement.

The SpectroRadiometric Calibration Assembly (SRCA) instrument was designed to perform spatial, radiometric, and spectral in-flight calibration of MODIS PFM. In spatial mode, it is used to characterize focal plane registration by measuring cross-track spatial shifts of each detector (channel), and in-track band centroid shifts. During this second year, we investigated the suitability of the SRCA to evaluate on-orbit the MODIS MTF. In order to do so, we needed to access information on the optical quality of the SRCA itself, particularly because it is not designed for MTF measurements.

1.1.1 The SRCA Spatial Mode data set

Test procedure PC17[1] uses the SRCA SIS lamps and the blackbody as sources to image a 12x5 km reticle onto the Focal Planes (FP). The results from these light scans are the cross-track responses of MODIS to the SRCA. Figure[2] 1 shows one such response for band 1 at the center channel. The right Edge Spread Function (ESF) is the response to the right edge. Likewise, the left ESF is the response to the reticle's left edge. The derivatives of the right and left ESFs give the right and left Line Spread Functions (LSFs), respectively.

The MTF profile in a given direction is the magnitude of the corresponding LSF's Fourier transform. Therefore, for each detector at each band, there are 4 measured cross-track MTFs, corresponding to the 2 edges of the reticle and the 2 sides of the scan mirror. Figure 2 shows the MTF for one mirror side and the right edge of channel 10 on band 4 (solid line).

1.1.2 Integration and Alignment Collimator (IAC) data set

Test procedure PC02[1] uses the IAC as the light source to provide an accurate data set from which the MODIS cross-track MTF can be estimated. Compared to other tests performed during the pre-launch period, PCO2 is an excellent source for MTF measurement since the IAC simulates a point source. In Figure 2, the MTF of channel 10 on band 4 is derived using the IAC data set (circles).

1.1.3 The Calibration of the SRCA

The SRCA MTF bandwidth (Figure 2) is less than the IAC MTF bandwidth, which results in a larger LSF, i.e. introduces more blur in the image, than the IAC LSF. The correction terms for SRCA calibration are obtained by dividing the SRCA derived MTF by the IAC-derived MTF at each frequency point. Figure 3 shows an averaged correction term for band 10 (solid line), and the uncertainties of each channel (error bars).

1.2 Error Analysis of the MODIS Adjacency Effect on the NDVI and EVI

This analysis is a collaboration between our project team and that of Alfredo Huete's. We have used their field measurements of growing cotton to simulate the effects of the MODIS Far Field Response (FFR) on estimation of vegetation indexes.

1.2.1 The MODIS FFR in relation to the adjacency effect

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[1] PC17and PC02 are laboratory test data.

[2] All figures and tables are at the end of the document.

The MODIS FFR is the result of spatial leakage in the Point Spread Function[3] (PSF). An ideal PSF is considered to be one in the IFOV and zero elsewhere. The MODIS scan direction LSF is modeled theoretically as a triangular function (Figure 4) with the width equal to 2*IFOV and 0 elsewhere. Point Spread Response (PSR) laboratory data (Figure 5) indicates that the MODIS scan direction LSF is much larger than the theoretical triangular function. This being the case, we define the FFR to include all measurable background.

The FFR contribution is an extension to the adjacency effect. The upper estimates obtained by summing the FFR for bands 1, 2, and 3 are Δ_{NIR}=29%, Δ_{red}=30%, and Δ_{blue}=8%, respectively. These percentages will be used as the adjacency effect background contribution.

1.2.2 MODIS Adjacency Effect Error Analysis

The adjacency effect resulting from the MODIS FFR on the Vegetation Index (VI) products, the NDVI and the EVI, appear to be non-negligible. We isolate the FFR effect on the VIs by assuming no atmosphere and no calibration uncertainties in the simulations using a linear mixing model.

The mixing model's foreground target is 2km, and the background target is 33km (Figure 5). The target is created using data from Alfredo Huete's group acquired with a Barnes Modular Multiband Radiometer (MMR). The targets are developing cotton at 0%, 20%, 40%, 60% and 95% coverage (Gossypium hirsutum L. var. DPL-70) with the Leaf Area Index ranging from 0-3.3. The spectral bands for the MMR are compared to those of MODIS in Table 1.

In the analysis, the FFR is the adjacency effect. The results are plotted in Figures 6, 7, and 8. Figure 6 shows the change in spectral signature of the foreground target. The curve 100% corresponds to Δ_{red}=30%, Δ_{NIR}=29%, and Δ_{blue}=8% adjacency effect. The adjacency effect reflectance values are used in Equations (1) and (2). The change in the spectral response changes the NDVI and EVI results. The NDVI is defined by the following

$$NDVI = \frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + \rho_{red}} \qquad (1)$$

and the EVI,

$$EVI = G\frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + C_1\rho_{red} - C_2\rho_{blue} + L} \qquad (2)$$

The terms ρ_{red}, ρ_{NIR}, and ρ_{blue} are reflectance; L and G are fixed. The adjacency effect is weighted at 100%, 75%, 50%, 25%, and 0% (Pure Signal) (Figures 7 and 8). As seen in the figures, the FFR adjacency effect is significant and should not be ignored. The NDVI is underestimated by Δ=0.18 and the EVI by Δ=0.3 for 100% FFR, where Δ is the error.

1.3 Summer 1999 Internship with Raytheon STX (RSTX)

During the internship, Francisco Rojas joined the MODIS Land Science Support Team (LSST) at NASA/GSFC. His assigned tasks included creating 160 control point templates for the LSST MODIS Error Analysis Algorithm using the Land Control Point Matching and Correlation program. [Reference MODIS Level 1A Earth Location, Algorithm Theoretical Basis Document Version 3.0, August 1997]. Creation of control point templates included auto-documenting scripts and control point images.

The internship benefited both LSST and our MODIS calibration project. We benefited by learning about the LSST MODIS HDF development tools. Currently, we are using this knowledge to enhance an in-house software package, tclSADIE, by incorporating the MODIS Application Program Interface (MAPI) library. This library will enable tclSADIE to read native HDF-EOS files in the MTF analysis.

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[3] The PSF is the 2-D version of the LSF.

During the summer, Mr. Rojas also attended the 1999 High Performance Computing Workshop, sponsored by the University Space Research Association. This experience has enhanced our project with knowledge about parallel programming concepts and availability of tools such as the Message Passing Interface (MPI) libraries. The workshop included hands on experience on the Cray T3E and the Beowulf Linux cluster development system architectures. Mr. Rojas will be applying distributed and parallel processing tools to his dissertation research on correction of MODIS data for band-to-band crosstalk.

2.0 Objectives and Planned Activities for Next Year

With the analysis of pre-launch MODIS test data complete, we will focus in the coming year on on-orbit MTF measurement. To characterize the MODIS MTF on-orbit, we will perform:

- MTF analysis using ground targets, SRCA data, and image comparison to ASTER and/or Landsat-7 ETM+
- development of MTF correction algorithms
- evaluation of MTF correction on certain MODIS science products, such as the NDVI and the EVI
- characterization of MTF stability

The ground MTF targets and NDVI/EVI analyses will be supported by ground truth field trips coinciding with satellite overpasses. These activities will achieve our primary research goal, validation of and correction for the MODIS spatial response.

2.1 Ground Targets , SRCA Data, and Image Comparisons

The MTF validation campaign will adhere to the schedule in Table 2. There is intentional overlap in the schedule. Part of the summer 2000 will be spent in field trip planning and data collection for our primary MTF targets. We are actively collecting imagery from Terra MODIS, Landsat 7 ETM+, and ASTER for the following primary targets: (1) All American Canal (AAC) near Yuma, Arizona, (2) Lake Tahoe on the California/Nevada border, and (3) lunar limb scans through the MODIS spaceview port. If future lunar scans through the Earth viewport are obtained, then that data will be used instead of spaceview port data. If any unforeseen issues arise with the primary targets, secondary targets are also being considered, the Nile river, Suez Canal, and the coast line of Gulf of Santa Clara, Mexico. Some coincident or near-coincident MODIS and ETM+ images are shown in Figures 9 - 11.

All of these targets are high contrast edge or line approximations. Lake Tahoe, the lunar scans, and the coast line in the Gulf of Santa Clara, Mexico, serve as edge targets. The AAC, Nile River and Suez Canal serve as line targets and require precise spatial measurements of their widths.

The SRCA on-orbit spatial mode scans will be used for long term stability MTF monitoring. Using our SRCA calibration correction function developed from pre-flight SRCA data, the on-orbit data can be used to generate another estimate of MODIS MTF. We are coordinating with MCST (Bruce Guenther) to obtain these special types of data, i.e. lunar and SRCA scans.

Finally, we will use two-image comparison techniques developed by Schowengerdt to derive a relative MTF for MODIS. The reference imagery will be any combination of available ASTER and ETM+ data, concident with MODIS acquisitions. We have requested a copy of the March 12, 2000, ASTER acquisition of Lake Tahoe from Dr. Anne Kahle at JPL, but it has been delayed because of on-going ASTER science team analysis.

2.2 MTF Correction

We will derive a small kernel, Finite Impulse Response (FIR) convolution filter that can be applied to Level 1B MODIS at-sensor radiance data. Demonstrations of its use will be integrated with the NDVI/EVI analysis.

2.3 MTF and MTF Correction Effects on Vegetation Indexes

The objective of this component of the research is to develop protocols that will allow us to better evaluate the MTF effect on MODIS vegetation indices (VIs), and the potential for producing more accurate VIs with MTF correction. Ongoing work by the Arizona Remote Sensing Center (S. Marsh) and the Terrestrial Biophysics and Remote Sensing Lab (A. Huete) at the A-7 ranch test site near Tucson, funded by the City of Tucson, is designed to discriminate short-term changes in vegetation condition driven by climate variability from long-term changes associated with historical land use practices and management. The A-7 project will span three years (2000-2003) and is designed to compare ground measures of vegetation cover and biomass at approximately 12 range and riparian test sites on the A-7 ranch with satellite-derived vegetation indices. In addition, the past condition of these test sites will be extracted from historical Landsat TM data available from the early 1980's and evaluated in conjunction with climate and land use practice. This effort at the A-7 ranch site will be combined with our MODIS MTF program to: (1) acquire and correlate nearly coincident field measures of range condition and riparian cover at the test site with data from MODIS, ASTER, and Landsat-7 ETM; (2) evaluate the differential of changing surface conditions with MODIS viewing geometry and MTF; and (3) document the usefulness of sensor MTF correction on our ability to establish relationships between vegetation condition, climate, and changing land-use.

2.4 MTF Stability

With a long series of earth image acquisitions, combined with lunar and on-orbit SRCA scans, we will be able to monitor the MTF over the remaining 18 months of the project. This period is long enough to observe any major degradations on-orbit since launch.

3.0 Publications

Three papers based on our MODIS pre-launch studies have been accepted to two conferences in the Summer 2000:

Rojas, Francisco, R. Schowengerdt , F. Keita and S. Biggar, “Error Propagation Analysis for the Moderate Resolution Imaging Spectroradiometer Laboratory Land Science Team’s Products based on Laboratory Data,” Proc. IEEE International Geoscience and Remote Sensing Symposium, IGARSS 2000, Honolulu, July 24-28, 2000.

Rojas, Francisco, R. Schowengerdt, A. Braga and S. Biggar, “Spatial Analysis of the MODIS PFM Channel Alignment and Far Field Response using Pre-resistor Fix Data,” Proc. SPIE 45th Annual Meeting, Conference on Earth Observing Systems V, San Diego, July 31-August 4, 2000.

Braga, Alexandre, F. Rojas, R. Schowengerdt and S. Biggar, “Calibration of the MODIS PFM SRCA for On-orbit, Cross-track MTF Measurement,” Proc. SPIE45th Annual Meeting, Conference on Earth Observing Systems V, San Diego, July 31-August 4, 2000.

Table 1. Comparison of MODIS and MMR Bands (Adapted from Pub. 1)

Spectral Region	MODIS		MMR	
	Band	Bandpass (µm)	Band	Bandpass (µm)
Blue	3	0.459-0.476	1	0.45-0.52
Red	1	0.620-0.670	3	0.63-0.69
NIR	2	0.841-0.876	4	0.76-0.90
Middle-IR	7	2.105-2.155	7	2.08-2.30

Table 2. Proposed schedule for 2000-01

Schedule	Activity	Task
May - August	Data acquisition	Determine candidate targets and continue on-orbit data acquisitions Collaborate with the Calibration Remote Sensing Group (UA) on field data acquisition scheduling to AAC and Lake Tahoe with MODIS, ETM+ and ASTER coverage
June - November	MTF analysis Data acquisition MTF stability Develop and test MTF correction algorithm	Determine the MTF from on-orbit data acquisitions Compare MTF results using different targets and methods Primary field Trip to AAC (canal width measurements) 6 month stability analysis (SRCA spatial mode and lunar limb spaceview scans)
December - April	MTF stability analysis Data acquisition Apply MTF correction	9 month MTF stability analysis Primary field trip to Lake Tahoe (ground snow cover) Implement MTF correction in VI analysis
May - July	MTF stability analysis Apply MTF correction	12 month MTF stability analysis Evaluate MTF correction in VI analysis
July - Sept	MTF stability analysis Prepare final report	18 month MTF stability analysis

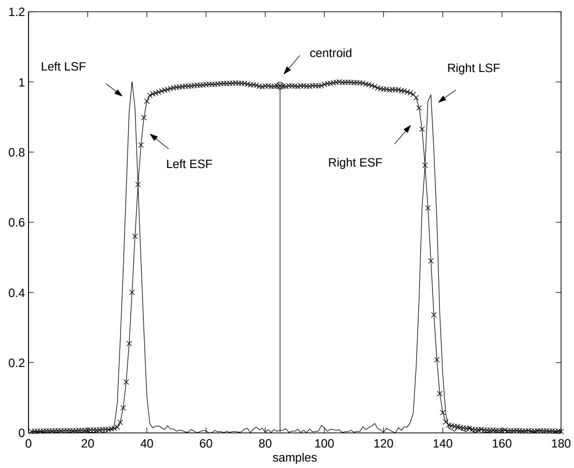


Figure 1. MODIS Response to SRCA at band 1, channel 20 (Xs). Right and Left LSFs (solid lines).

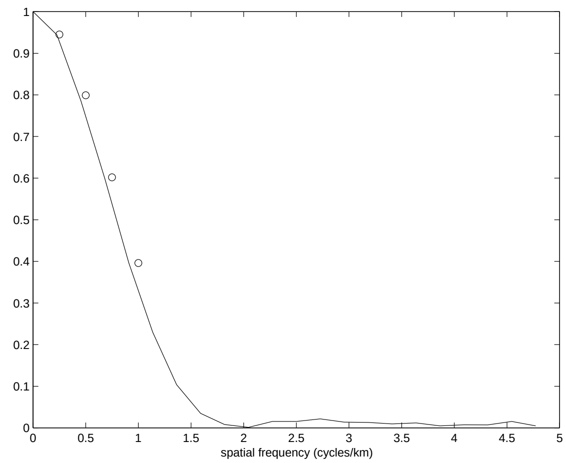


Figure 2. MTF derived from IAC (circles) and SRCA (line), for band 4, channel 10.

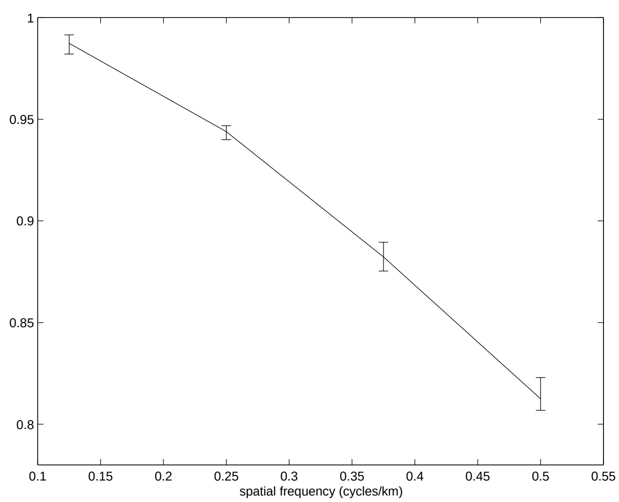


Figure 3. Correction term for the SRCA response. Channel-wise (error bars), and band-averaged (line).

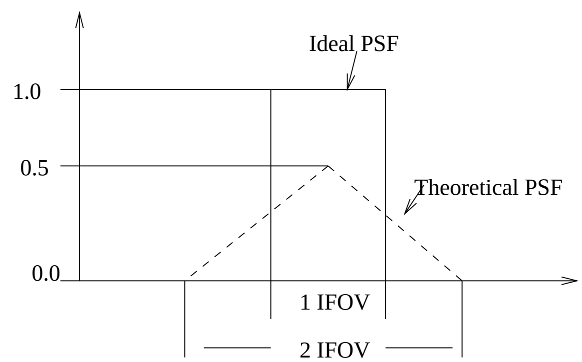


Figure 4. The ideal and theoretical MODIS triangular cross-track (along-scan) PSF.

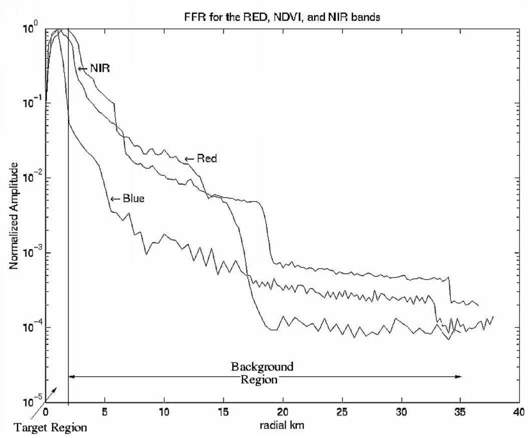


Figure 5. The FFR estimate for the MODIS band 1 (Red), band 2 (NIR), and band 3 (Blue), obtained ensquared energy analysis of the pre-launch PSR data, as described in the 1999 annual report.

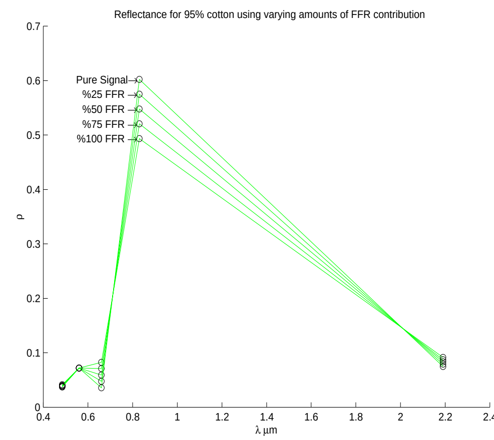


Figure 6. The spectral response percentage of the FFR. Cotton surrounded by a soil background.

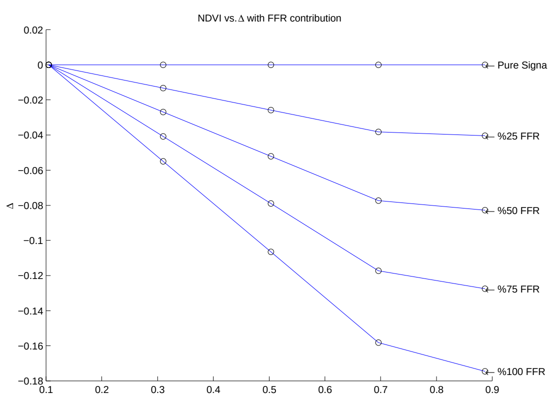


Figure 7. _ vs. NDVI with background soil target.

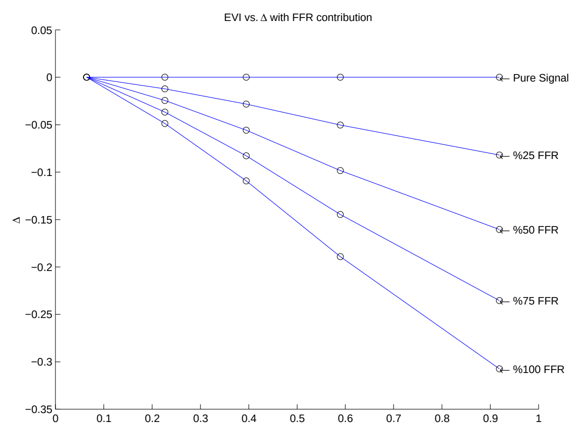


Figure 8. _ vs. EVI with background soil target.

Figure 9. Landsat TM images of two of our targets, the AAC and Lake Tahoe

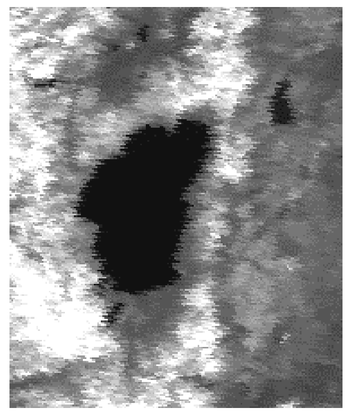
Date	**AAC**	**Lake Tahoe**
Landsat ETM+ April 26, 2000		
MODIS Band 2 Aggregated at 500m 1st order -rectified April 24, 2000		

Figure 10. MODIS Level 2 Surface Reflectance data as downloaded from the EOS Gateway and approximately geocoded using a first-order affine transformation.

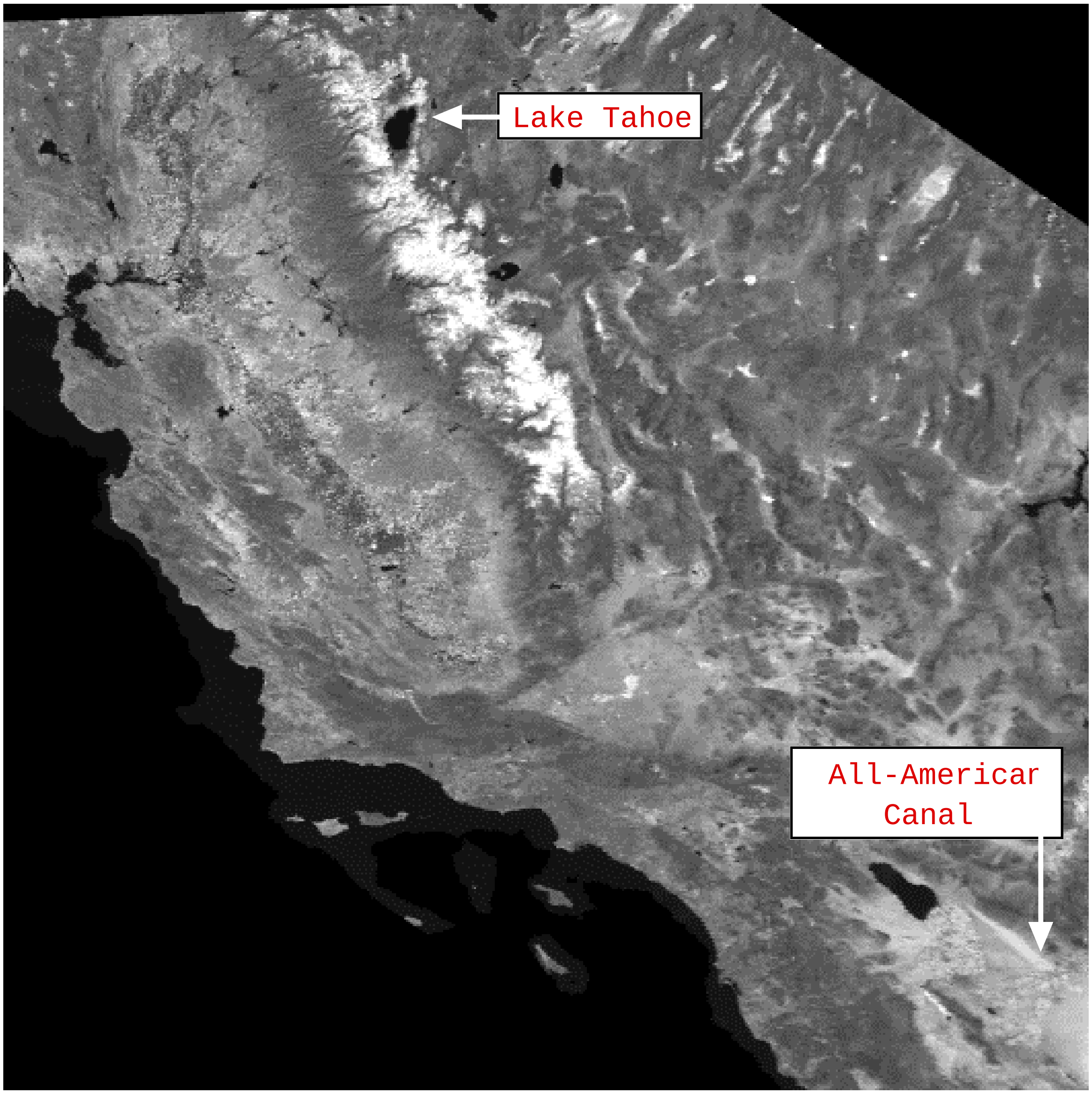
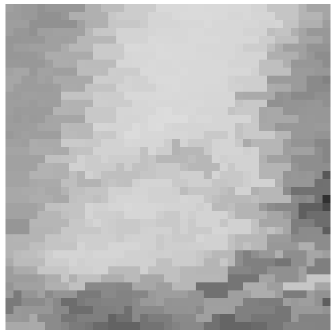
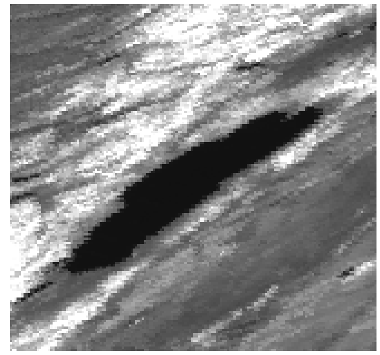
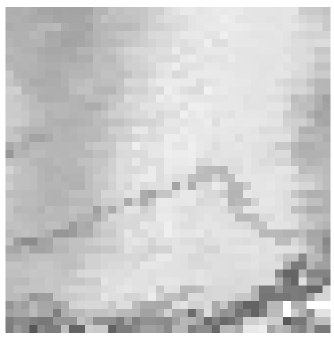
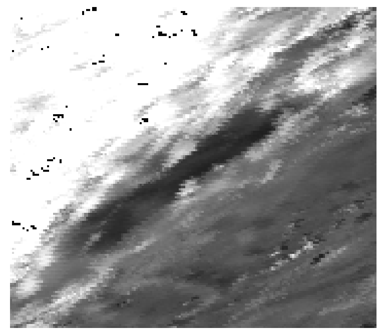
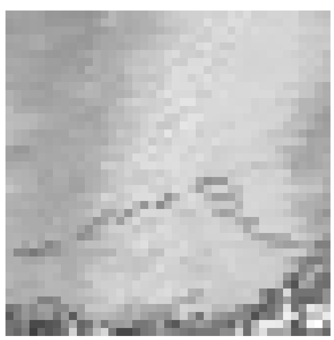
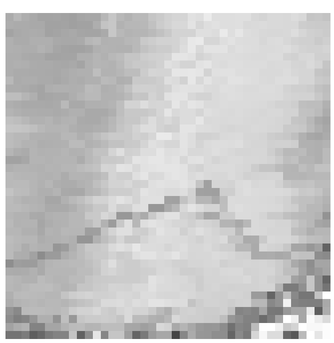
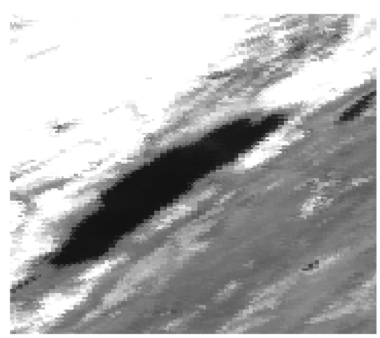
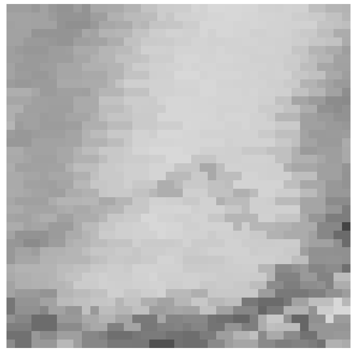
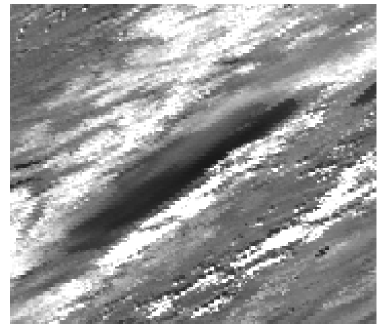
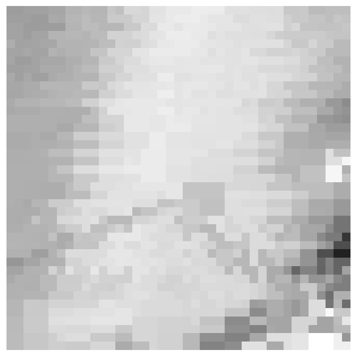
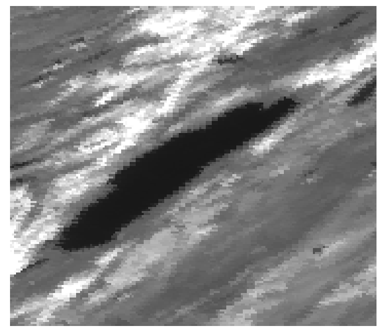


Figure 11. MODIS images on 7 dates of the two targets in Figure 10. Level 2 Surface Reflectance is shown; we will use Level 1B Radiance data for the MTF analysis.

Date	**AAC**	**Lake Tahoe**
April 02, 2000		
April 15, 2000		
April 17, 2000		
April 19, 2000		

April 20, 2000		
April 23, 2000		
April 24, 2000